Technical Status of ILC

Completing the Technical Design Phase

Presentation to SiD prepared by:

Marc Ross (SLAC)

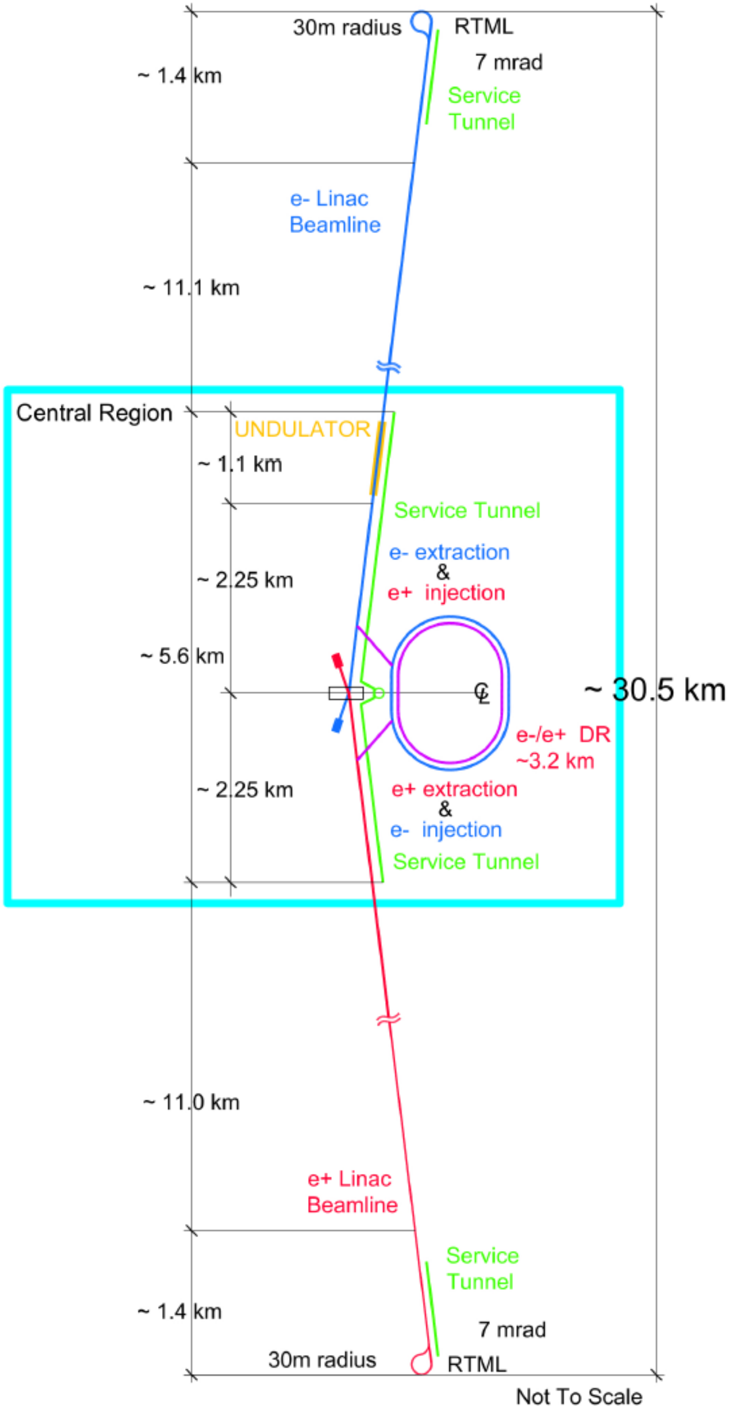
January 16, 2013

Completing the TDP: Outline

- TDP Goals:
  - R & D to enable Project Proposal and updated Value estimate – with Cost Containment
  - Technology Transfer
    - development a strong industrial base
- Technical Design Report:
  - Consists of two parts: 1) R & D Report and 2) Design Description
- Beam Test Facilities:
  - SRF Linac: Fermilab NML, DESY E-XFEL and FLASH, KEK STF
  - Beam Dynamics: Cornell CesrTA (2008 – 2010)
  - Beam Tuning: KEK ATF2
- Production / Industrialization:
  - CEBAF Upgrade and E-XFEL

ILC 2012: Project Overview

- 35 km of beamline tunnel,
  - 38 km non-SRF b-line, 22 km SRF ML
- 2007: 6.6 B$ + 24e6 hours lab labor
  - 2012 – now under review
  - non-SRF cost 100K/meter;
  - SRF linac cost 250K/meter (incl.)
  - for ½ Ecm – 60 to 70% cost;
- 160 MW AC at 500 GeV Ecm;
  - 10.4 MW total beam power
  - for ½ Ecm – 120 MW AC
- 9 year construction 500 GeV
  - for ½ Ecm - 7 to 8 years



Readiness to propose ILC:

- Ready to start; no more R & D needed. Next step: detailed design
- Component and system tests have proved technical viability:
  - industrial capacity utilized → also input for cost study
- Full scale demonstrations are not practical
  - e-cloud, ATF2, FFTB, E-166, TTF/FLASH, etc. subsystem tests
  - critical to understand how system tests scale and to study the largest systems practical
- ILC SRF R & D met (or nearly met) goals:
  - Vertical test accelerating gradient and Q_0 of 35MV/m and 8e9.
  - Industrial cavity fabrication production yield of 90%.
  - Cryomodule average accelerating gradient of 31.5 MV/m.
  - System test with full beam current operation nominal gradient
  - Industrial production of 800 cavities / 100 cryomodules EXFEL
  - Multiple companies qualified to fabricate full-performance cavities.

Technical Issues

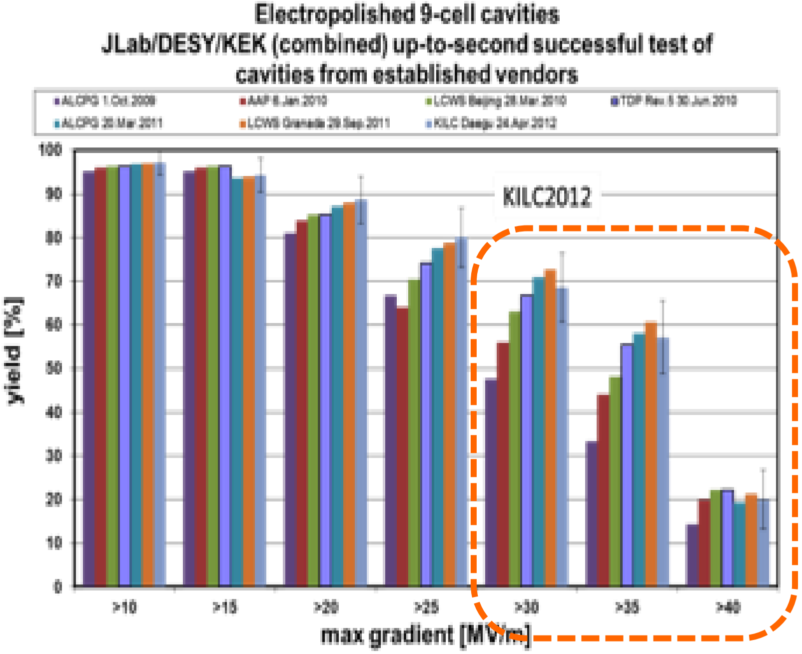
SRF

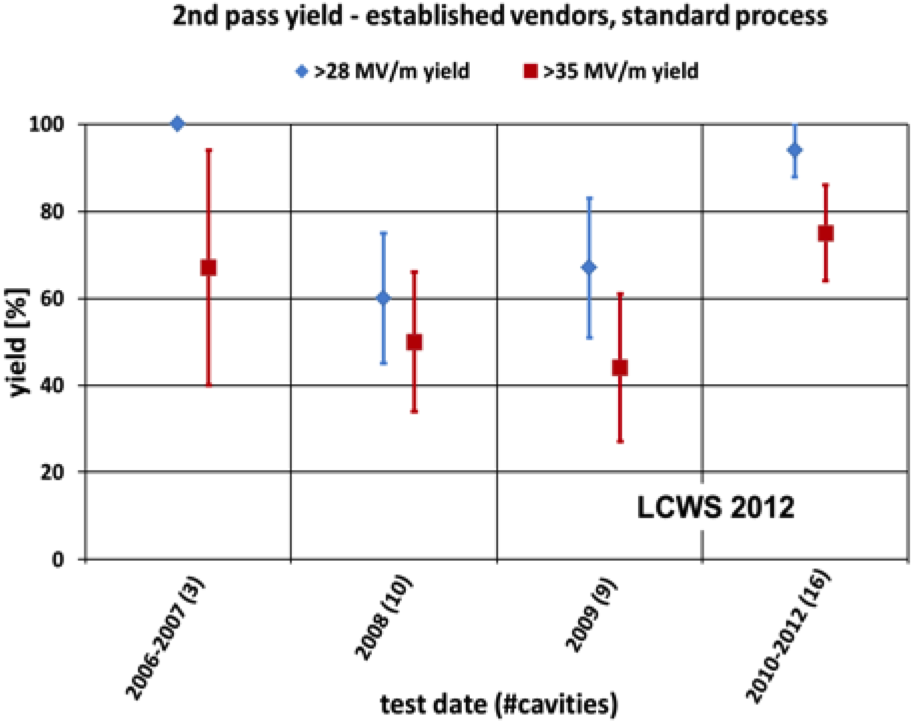
- **XFEL** actual performance (2011 – *2015 (start ops)* - …)
  - » Follow-on studies to reduce technical risk (and cost)

e+

- below 150 GeV e- E_beam, **undulator source e+ yield** low
  - → 10 Hz e- linac operation ← (in baseline)
  - » Damping done in 100 ms (not 200 ms)
    - additional wiggler and RF
    - e+ ring is ‘empty’ for 100 ms,
    - transient beam loading requires 15% added RF power
  - » All e- linacs run at 10 Hz.
  - » The positron production e- pulse (150 GeV beam) must be extracted and dumped
  - → Helical undulator R & D: increase length and / or reduce period from 11.5 to 9 cm ←

Cavity Gradient:
Production Yield Progress since 2006


Electropolished 9-cell cavities
JLab/DESY/KEK (combined) up-to-second successful test of cavities from established vendors

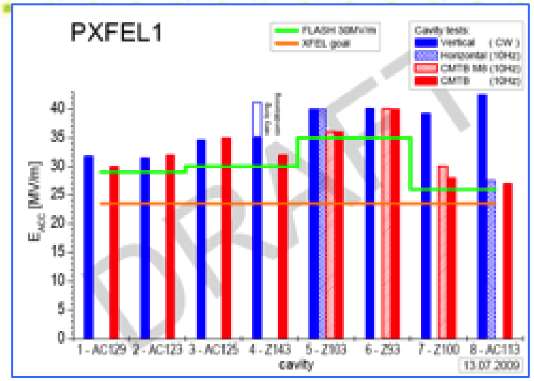

2nd pass yield - established vendors, standard process

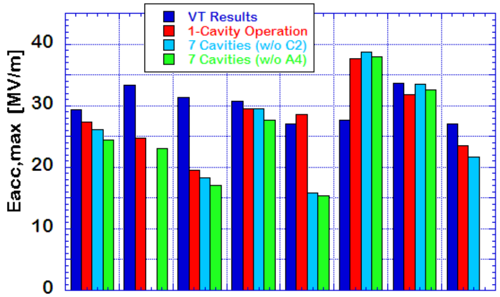
- Integrated statistics since 2006 in 2nd pass yield
- Max. gradient achieved: > 45 MV/m

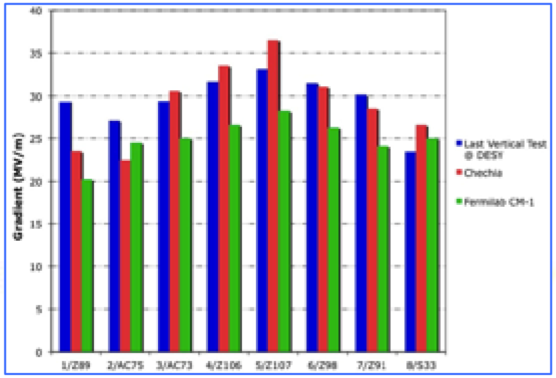
2nd pass statistics for 2010 ~ 2012 period:
Production yield: 94 % at > 28 MV/m,
Average gradient: 37.1 MV/m

Progress in SCRF System Tests

- **DESY: FLASH**
  - SRF-CM string + Beam,
    - ACC7/PXFEL1 < 32 MV/m >
  - 9 mA beam, 2009
  - 800μs, 4.5mA beam, 2012
- **KEK: STF**
  - S1-Global: complete, 2010
    - Cavity string : < 26 MV/m>
  - Quantum Beam : 1 ms
  - CM1 + Beam, in 2014
- **FNAL: NML/ASTA**
  - CM1 test complete
  - CM2 operation, in 2013
  - CM2 + Beam, beyond 2013







FLASH 9mA Expt achievements: 2009-mid 2012

High beam power and long bunch-trains *(Sept 2009)*

Metric	ILC Goal	Achieved
Macro-pulse current	9mA	9mA
Bunches per pulse	2400 x 3nC (3MHz)	1800 x 3nC 2400 x 2nC
Cavities operating at high gradients, close to quench	31.5MV/m +/-20%	4 cavities > 30MV/m

Gradient operating margins *(Feb 2012)*

Metric	ILC Goal	Achieved
Cavity gradient flatness (all cavities in vector sum)	2% ΔV/V (800μs, 5.8mA) (800μs, 9mA)	<0.3% ΔV/V (800μs, 4.5mA) *First tests of automation for Pk/Ql control*
Gradient operating margin	All cavities operating within 3% of quench limits	Some cavities within ~5% of quench (800us, 4.5mA) *First tests of operations strategies for gradients close to quench*
Energy Stability	0.1% rms at 250GeV	<0.15% p-p (0.4ms) <0.02% rms (5Hz)

R & D towards ILC – Outline

(an update)

- SRF Linac construction projects:
  - CEBAF 12 GeV upgrade (CW accelerator, cryo power limit)
  - E-XFEL
- ILC SRF at Fermilab
  - Cryomodule ‘CM2’
- High Level RF at SLAC
  - Klystron Cluster

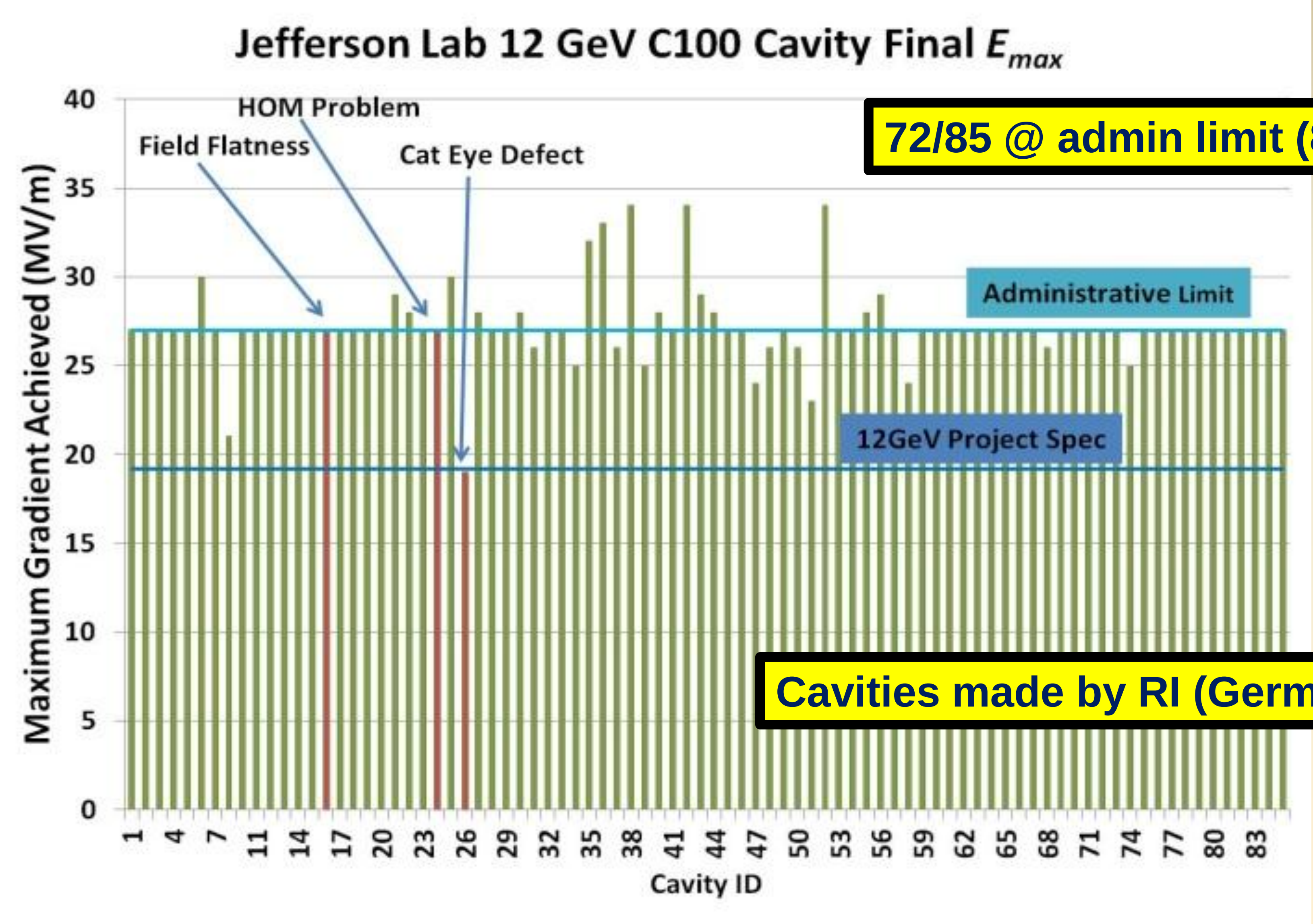
- Beam tuning – Accelerator Test Facility at KEK
  - Creating small beams

Storyline for 12 GeV Cavities

- 2000-2002 **Design** and **prototypes**
- After prototype set, cavity **design optimization** to adjust input **coupling**, reduce fundamental field at **HOM couplers** (thermal issue), and get as-welded cavity closer to target **frequency**.
- **Default surface prep**: heavy BCP [all tests met project requirements]
- Outside-of-project effort to apply **controlled EP** encouraged by **ILC R&D** work, also **streamlined preparation process** developed.
- Result: **Increased *Q*** in the 17 – 24 MV/m range from **EP** added Technical Contingency in cryoload with minimal, if any, cost impact.
  → Project acceptance.
- Cavity acceptance test **performance exceeded requirements**.
- Principal remaining **performance-limiting phenomenon** was **field emission**, but none with enough significance to not meet project requirements.

CEBAF 12 GeV upgrade

12 GeV cavities:overall performance



72/85 @ admin limit (85%)

Cavities made by RI (Germany)

Jefferson Lab

CEBAF 12 GeV upgrade

Cryomodule design and production

The design of the **C100** is an evolution from the **C20** CEBAF cryomodule

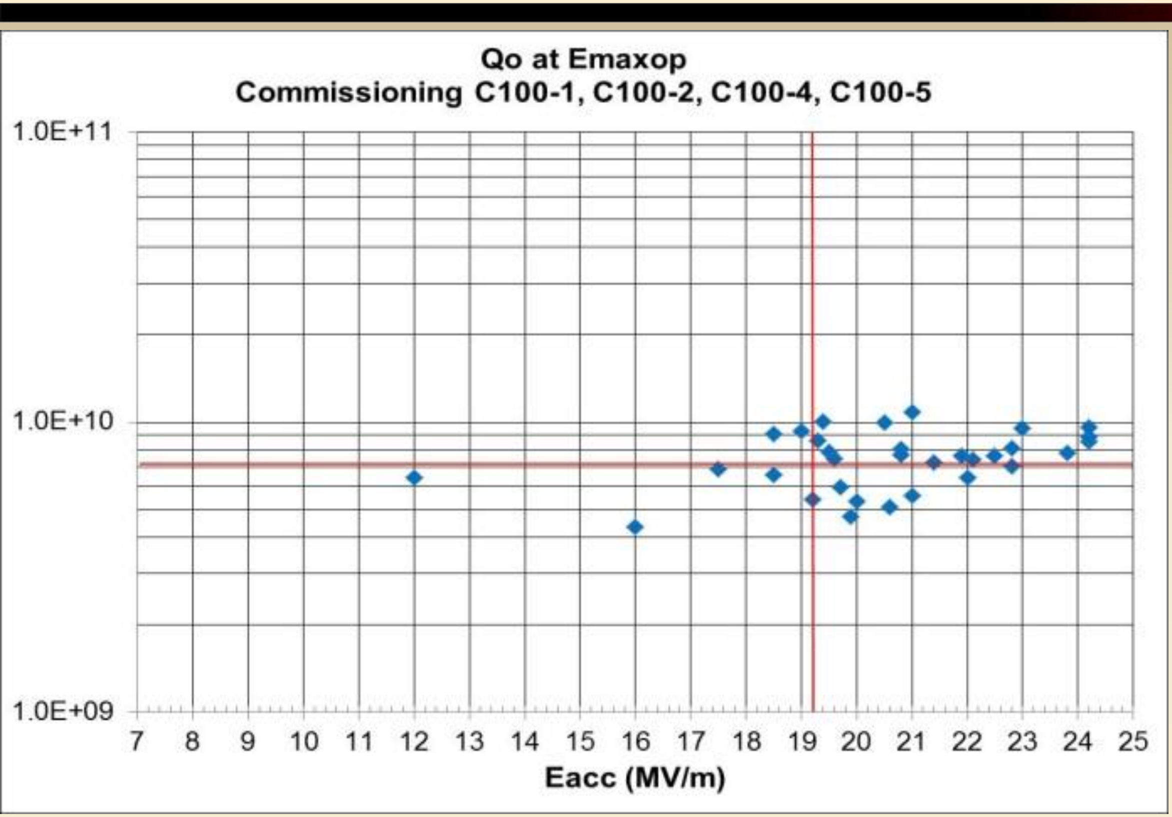
Experience from the **C50 program** (*reduce field emission* and *raised gradient from 5.5 MV/m to 12.5 MV/m* for 10 of the weakest C20 cryomodules)

Output needed: **98 MV**, designed for **108 MV**

Primary components procured, assembly and qualification at JLAB

CEBAF 12 GeV upgrade:
10 CM total each with 8 cavities

12 GeV Upgrade Cryomodule Performance



2.07 K

CEBAF 12 GeV Cryomodules
<V_test> ≈ 21 MV/m
<V_ops> ≈ 13.5 MV/m

Project goals met - (much lower gradient than ILC for CW ops)
Field emission important

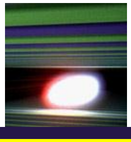
Cryomodule Energy Gain (MeV)

	Acceptance	Test in Tunnel	Ops
C100-1	111.7	104.3	94.5
C100-2	117.5	109.6	108
C100-3	118.7		
C100-4	115.1	105.8	
C100-5	108.2	109.9	

Current status of activities at RI and EZ

- Set up of the **infrastructure** for XFEL cavity treatment on companies RI and E. Zanon **is mainly finished**
- **Infrastructure qualification close to the end**
- Preseries cavities (PCV): **4 produced by RI, 8 by EZ** (Mechanical Construction)
- **Main EP** treatment under way on the first PCVs
- As soon as the RCV will have qualified the full surface process, the **PCV will start the rest surface treatment**
- **First PCV will be ready by Christmas 2012** fully treated and integrated in the HT
- **First series production: begin 2013**
- The **DESY specification is mostly implemented** into the work instruction and QM documents

XFEL cavity production



10x more cavities than JLAB

- **No performance guaranty by the vendors**, i.e. the risk of unexpected low gradient or field emission is taken over by DESY (responsibility for re-treatment).
- Goal: average usable XFEL gradient **24.3 MV/m** at Qo=$1x10^{10}$, X-Rays <$1x10^{-2}$mGy/min)
- First series cavities (PCV) **to be delivered end 2012 – begin 2013**
- All cavities to be delivered till **end 2014 – begin 2015**
- Delivery rate: about **8 CVs/week**
- Supervision of the CV production: **DESY & INFN/LASA**

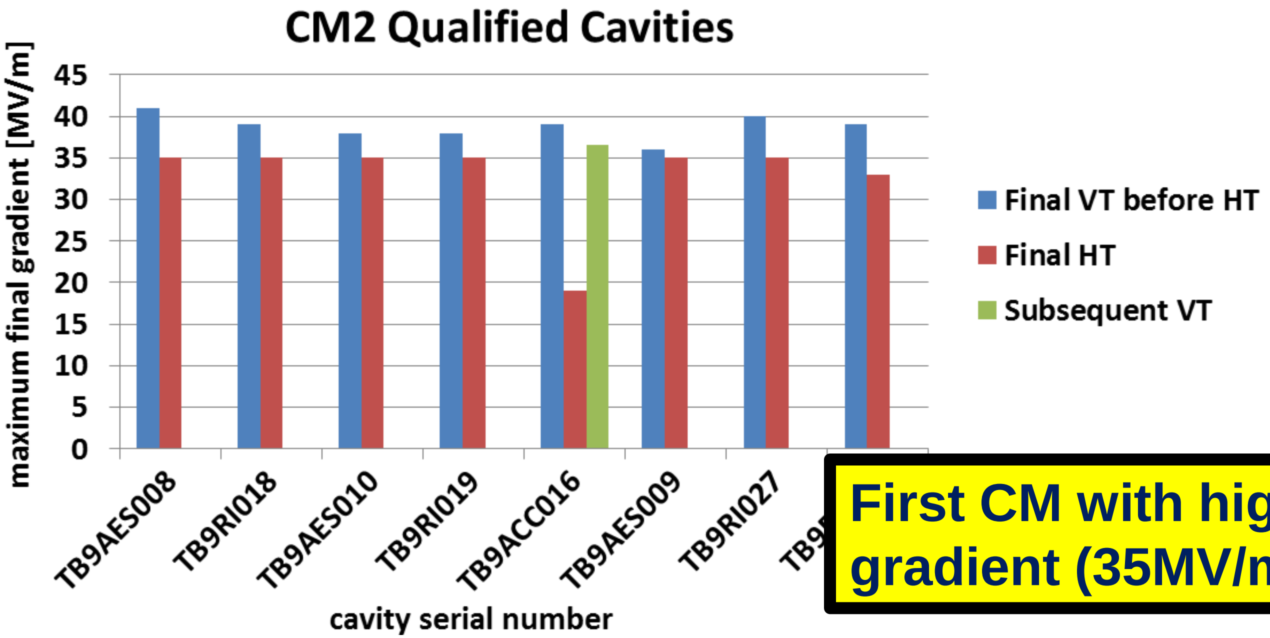
FNAL CM2 Status Report

Tug Arkan, Camille Ginsburg

1/10/2013

Fermilab ‘ILC-style’ CM2

Cryomodule CM2



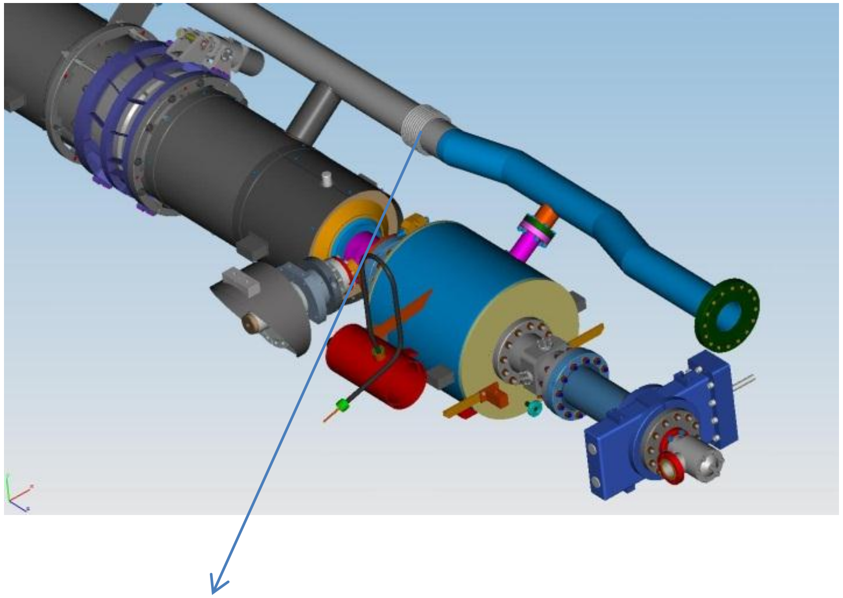
First CM with high gradient (35MV/m cavities)

- CM2 is a 1.3 GHz Type III+ design cryomodule, consisting of 8 cavities and a magnet package at the end
- CM2 is the second cryomodule of this type assembled at the Cryomodule Assembly Facility (CAF) in Fermilab
- All CM2 cavities were processed and vertically tested at JLab, and dressed and horizontally tested at FNAL
- All CM2 cavities reached 35 MV/m gradient in final test prior to assembly

Fermilab 'ILC-style' CM2

Helium Circuit Vacuum Leak

- A vacuum leak was found at NML during the incoming leak checks
- CM2 was partially disassembled at CAF to repair the leak
- We spent ~3 months hunting for the leak with various leak checks and pressure tests
- The Ti bellows showed a leak similar to the one observed at NML one morning and the leak disappeared again in the afternoon (Strange behavior)
- We replaced the Ti bellows and started to reassemble the CM2 in November 2012
- Ti bellows was sent to a vendor for further investigation to learn about this strange leak/ no leak behavior
- We hope to get some useful results from this investigation so that we can have a lessons learned from this experience. This experience cost us almost 6~8 months for the testing of the CM2 at NML



Ti bellows between the magnet and cavity #8 bellows was replaced

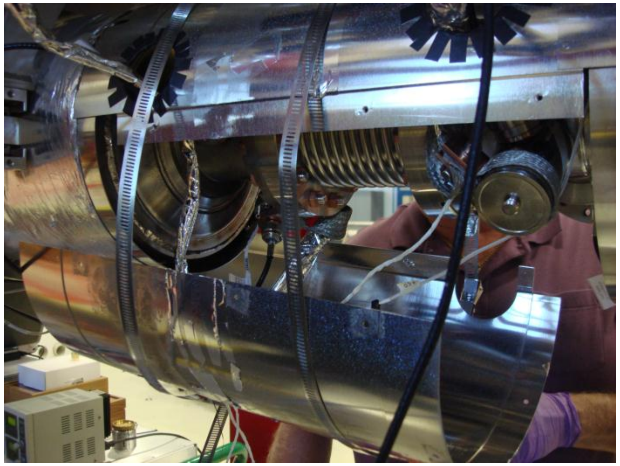
CM2 Re-Assembly Status

- As of January 8, 2013, the cold of mass of CM2 is inside of its vacuum vessel
- Alignment is currently progressing
- Warm end coupler assembly will be next
- Quality assurance and leak checks (insulating vacuum, helium circuit, beamline vacuum) at CAF before transporting the module to NML

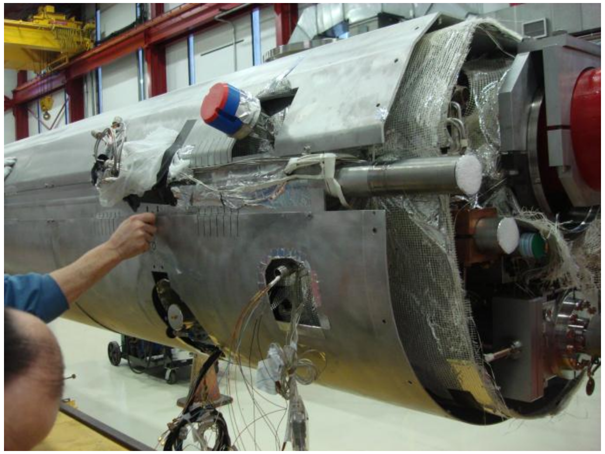
Fermilab 'ILC-style' CM2

Pictures from the Re-Assembly


CM2 cold mass was partially disassembled to repair the leak


After the alignment of the cavities, the interconnect magnetic shielding was installed


Movement of cold mass to Big Bertha cantilever fixture

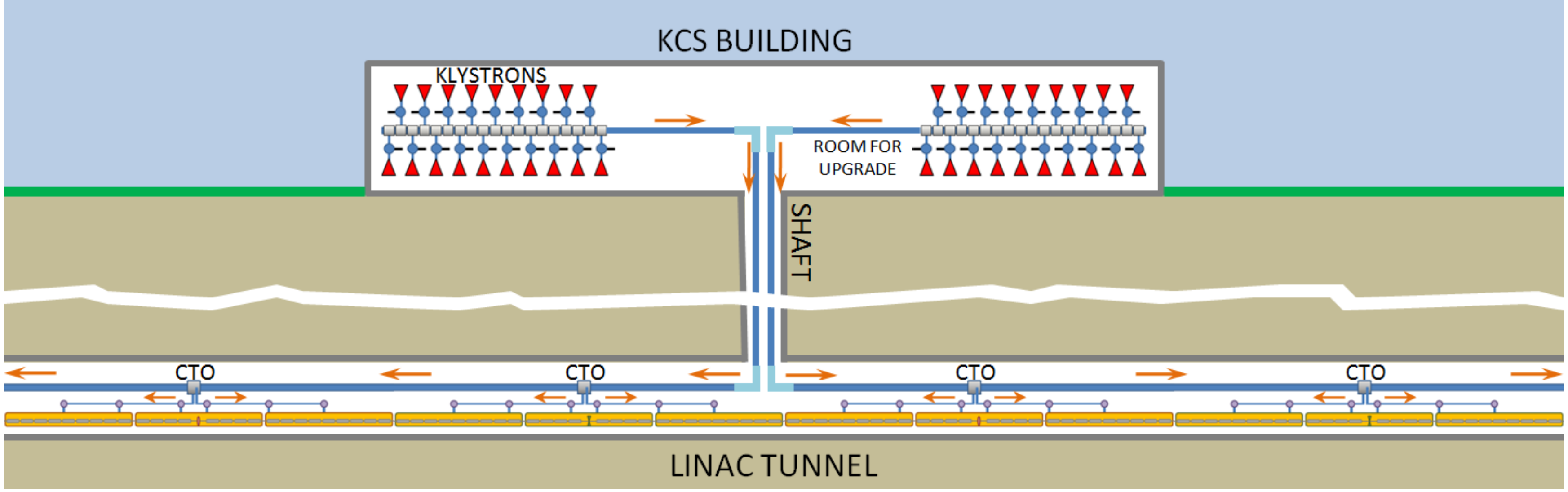

Aluminum heat shields welding and thermal anchoring of the cables/wires


MLI installed


Vacuum vessel assembly onto the cold mass

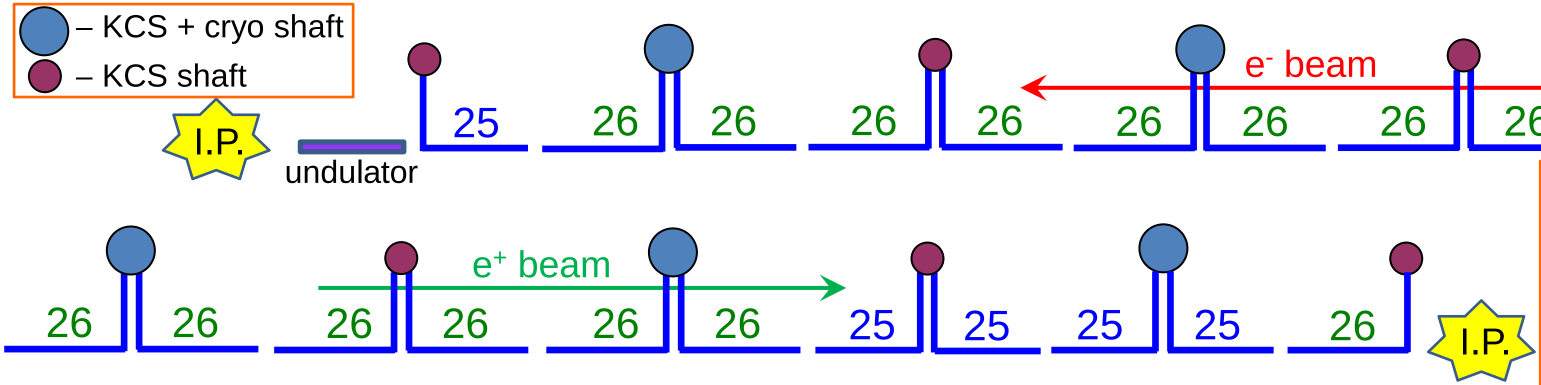
SLAC: RF Distribution

Klystron Cluster Scheme



- RF power sources clustered in surface buildings.
- Power combined, transported through overmoded waveguide, and tapped off locally at each ML Unit.
- Two KCS systems per building/shaft feed upstream and downstream, ~1 km each.

Shaft Layout and ML Units Powered

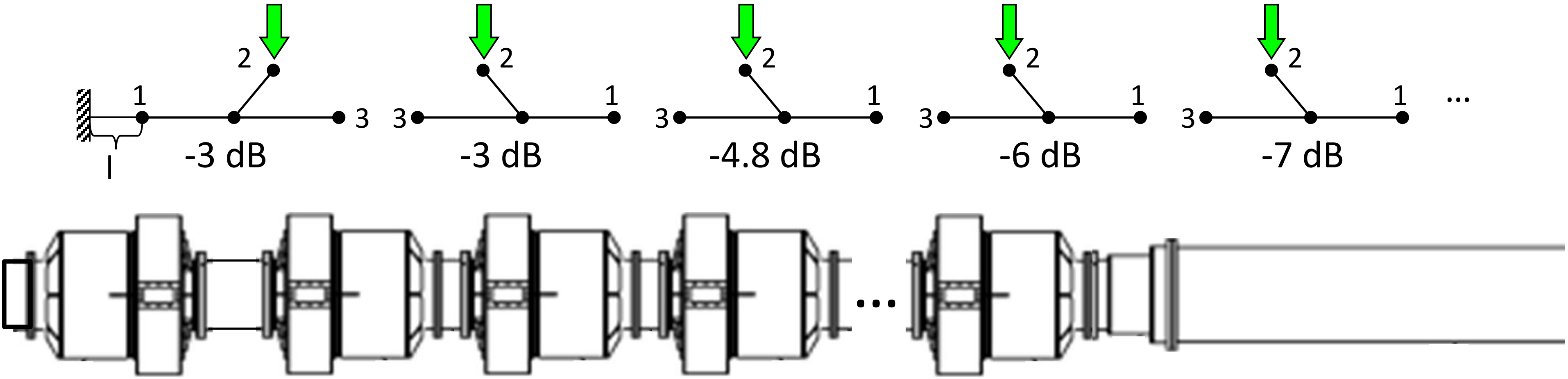


main linac totals:
12 shafts
22 KCS systems
567 rf units (285+282)
1,701 cryomodules
14,742 cavities

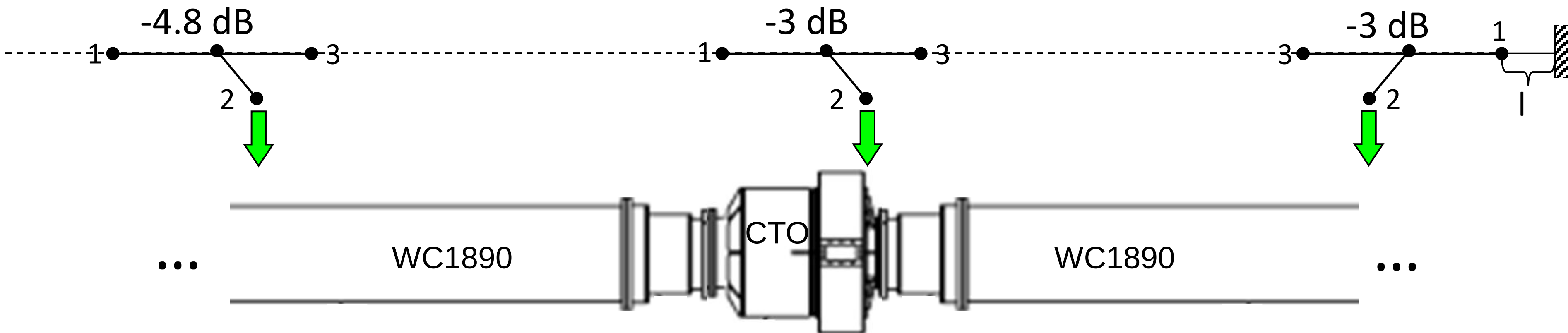
SLAC: RF Distribution

Combining and Tapping Off Power

Combine power from 19 klystrons – effectively a 190 MW klystron



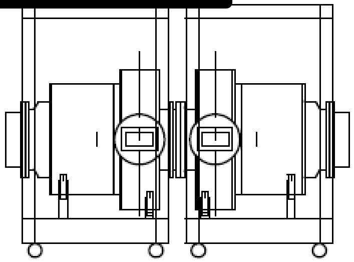
Tap-Off 10 MW every 38 m (three cryomodules)



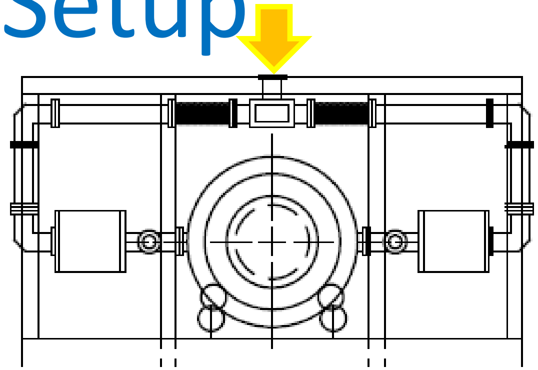
SLAC: RF Distribution

Ten Meter Test Setup

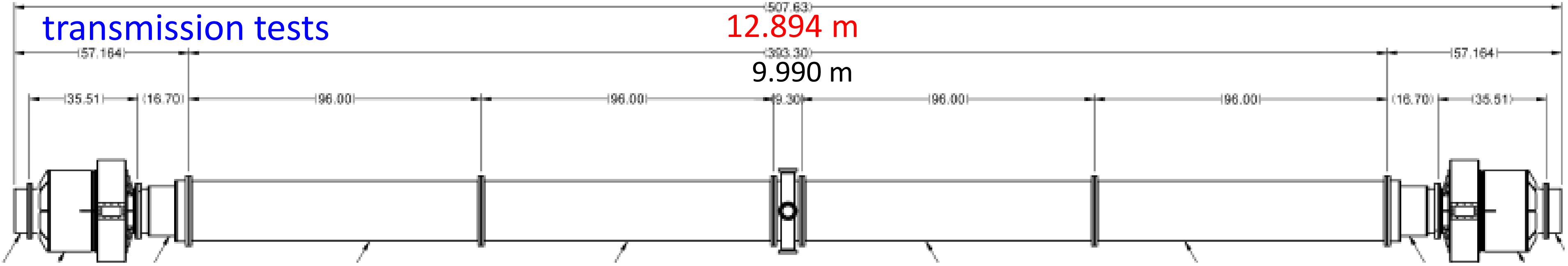
CTO cold tests



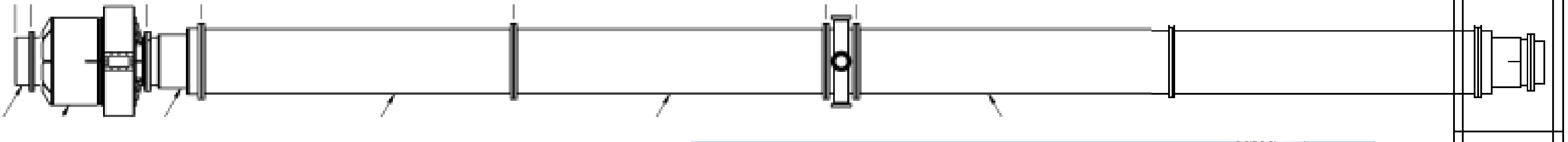
input assembly



transmission tests



resonant line tests

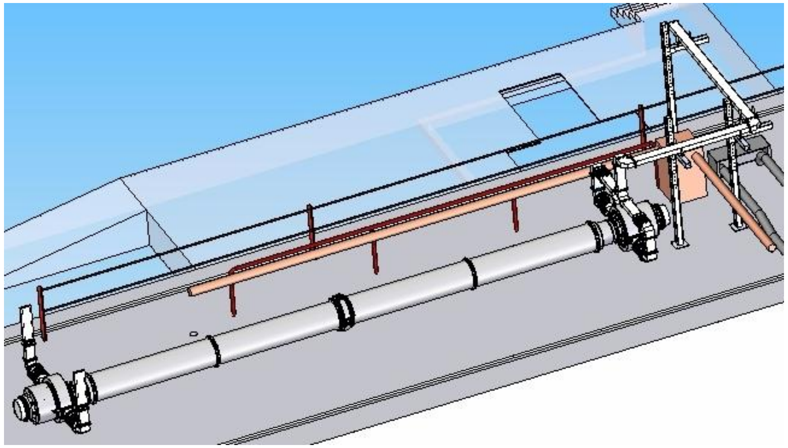


Location:

Roof of NLCTA bunker

Power source:

SNS modulator and
Thales “5 MW” klystron



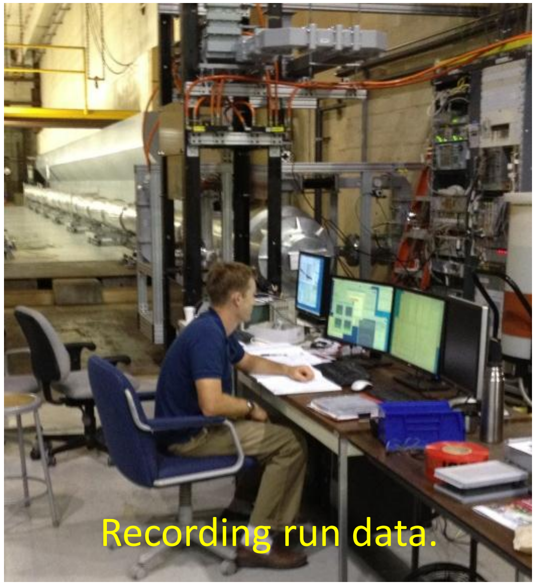
SLAC: RF Distribution

Forty Meter Test Setup

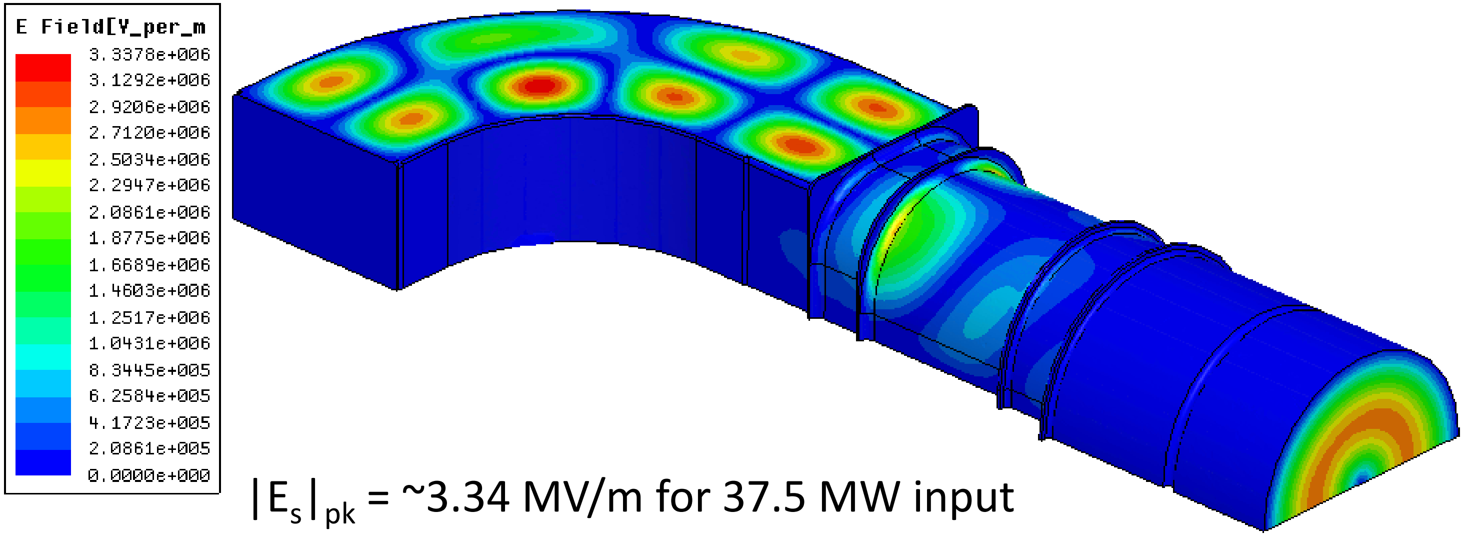

CTO coupling RF power from P1 Marx-driven Toshiba MBK into TE_{01} mode in resonant line using KEK circulator.


40 m of pressurized (30 psig) , 0.48m diameter circular waveguide.


Shorted bend with input mode converter at end of run.


Recording run data.

Surface Electric Field in 90 Degree Bend

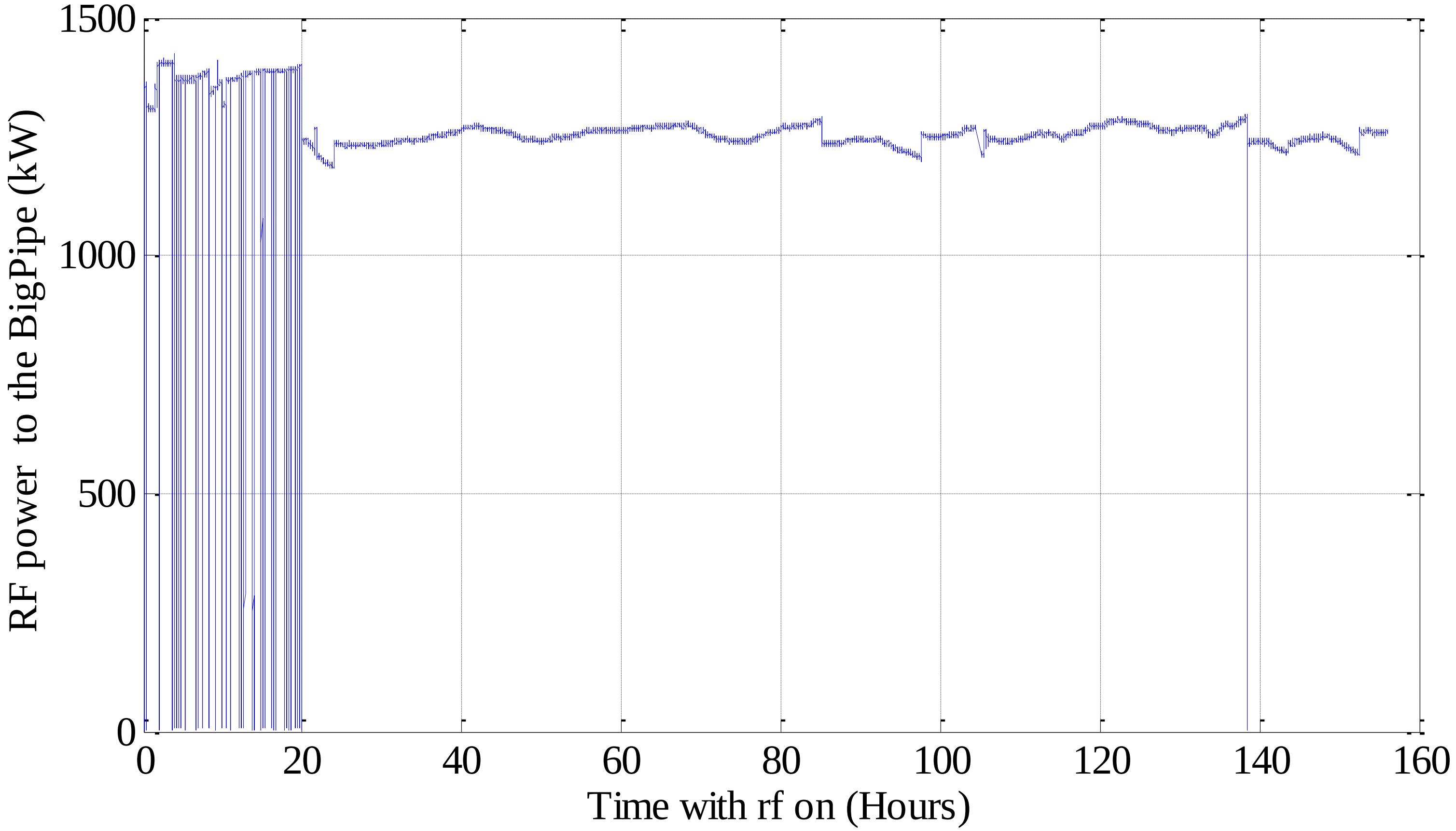


$|E_s|_{pk}$ = ~3.34 MV/m for 37.5 MW input
(= 75 MW full geometry → 300 MW TW equiv. at SW anti-nodes)

Equivalent to 72 MW TW in WR650 !

SLAC: RF Distribution

Second Run: 1.25 MW input (313 MW field equivalent – ILC needs only 190 MW initially), one breakdown in 140 hours with 1.6 ms pulses at 3 Hz



1. Coupling coefficient β = 1.17
2. Power needed for equivalent field of 300 MW, Pin = 1.18 MW.

ATF2 Program Status

Glen White, SLAC

January 2013

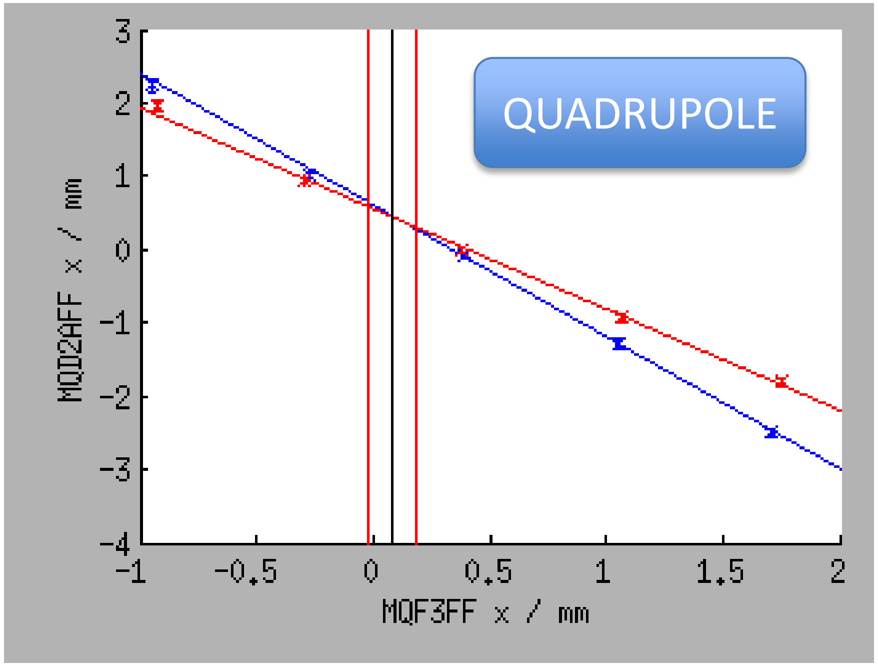
Some Highlights of Fall 2012 Operations

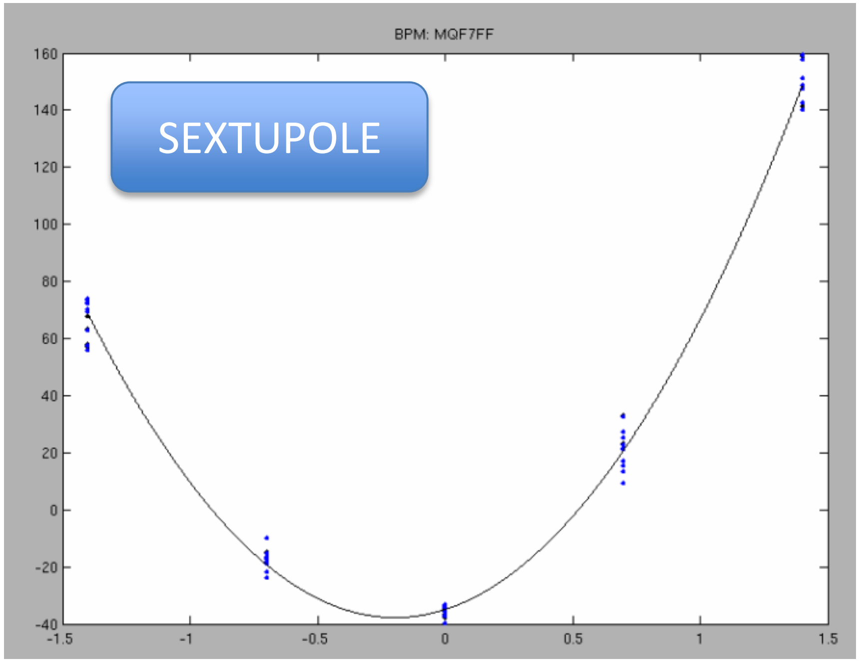
- 100% ATF2 operations
  - 8 weeks Oct, Nov, Dec
  - Include ~20 non-KEK staff as part of machine operations team
- Operations with nominal vertical beta optics for first time
  - Matched in extraction line with OTR system (BMAG < 1.01)
  - Confirmed correct propagation to IP
  - Low backgrounds for IP beamsize monitor system
- Installation and use of 4 skew-sextupole magnets for non-linear IP correction knobs
  - Y22 and Y26 used with effect
- Replacement of QF1FF with old PEPII LER quadrupole
  - Much improved multipole fields
  - Will allow for design IP horizontal beta function optics
    - Although still using 10X now for safety
- Suspect wakefield-domination of IP vertical beam size ~<300nm
  - Running at low charge (~150 pC) and long bunch length (~>10mm) enabled systematic beam operations and studies with IPBSM in 30-degree mode for first time.
- First successful observation of modulation with IPBSM in 174-degree mode of operations
  - Beam tuned to <70nm
  - Delivered IP spot size now smaller than FFTB published record.

Most Important Outstanding Issues

- **Wakefields**
  - See very strong dependence of IP beam size on charge and bunch length
  - Need to identify and mitigate wakefield sources
    - Suspect c-band cavity wakes in FFS
- **Extracted emittance**
  - EXT measurements > DR
  - ~30-35pm high charge, ~20pm low charge in EXT, target is 12pm extracted emittance
  - Suspect extraction kicker/septa system
    - Continue with studies to find good extraction orbit and hardware alignment (11pm extracted in 2010)
- Full tuning treatment applied in **IPBSM 174-degree mode**
  - Not yet performed, ran out of time in Dec
  - Quantify effects degrading beam size above emittance-limit.

Beam-Based Alignment (BPM-Magnet Field Centres)

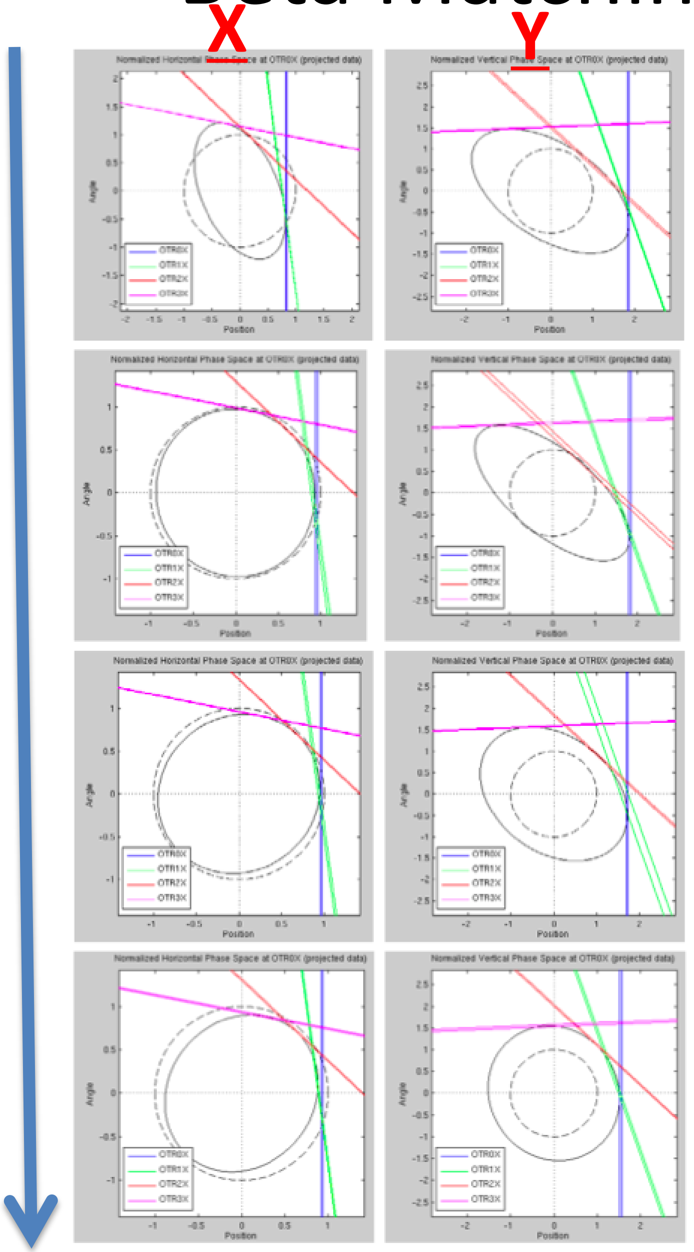




- Measure offsets of BPMs to centres of magnets they are attached to so BPM system reads out offsets with respect to magnets.
- Use magnet movers in FFS
- Between 5 and 50um alignment accuracy depending on number of downstream BPMs available and their relative phase advances.

KEK and Collaboration: Beam Tuning

Beta Matching With Multi - OTR System



name	match0	match1	match2	match3	design
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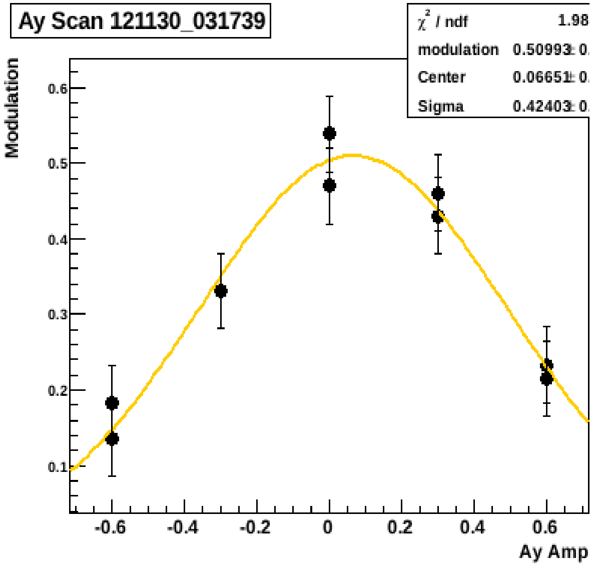
EmitX	1.7894	1.8228	1.7587	1.5860	
BmagX	1.1946	1.0013	1.0026	1.0076	1.0000
EmBmX	2.1376	1.8251	1.7633	1.5981	
BetaX	4.7239	6.0386	6.4327	6.2257	6.3052
AlphaX	-2.8890	-4.2795	-4.6550	-4.5596	-4.4943
EmitY	28.4846	25.7572	30.8175	28.2300	
BmagY	1.2000	1.3489	1.0554	1.0034	1.0000
EmBmY	34.1808	34.7439	32.5253	28.3262	
BetaY	9.1308	9.4923	7.1151	6.0766	6.1903
AlphaY	4.4037	4.8369	3.2854	2.6087	2.5763
QF1X	50.682	50.947	50.812	50.812	49.024
QD2X	42.865	43.035	43.312	43.312	42.865
QF3X	30.497	30.724	30.800	30.800	30.498
QF4X	30.863	30.710	30.636	30.636	30.864
QD5X	41.940	42.083	41.995	41.995	41.940
QF6X	52.983	52.753	52.692	52.692	51.556
QF7X	54.600	54.524	57.931	57.931	54.601
QD8X	26.862	26.850	27.005	27.005	26.863
QF9X	34.701	36.133	36.027	36.027	34.702
QD10X	52.965	51.764	56.860	56.860	52.964

Upstream quads within inflector

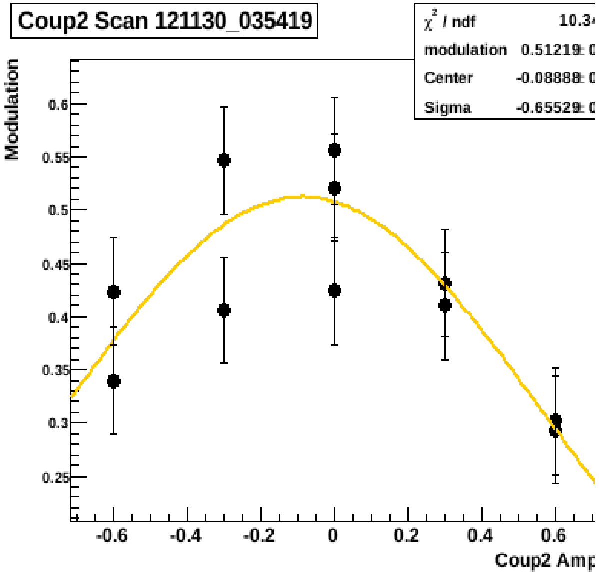
KEK and Collaboration: Beam Tuning

IP Multi-Knob Scans (linear)

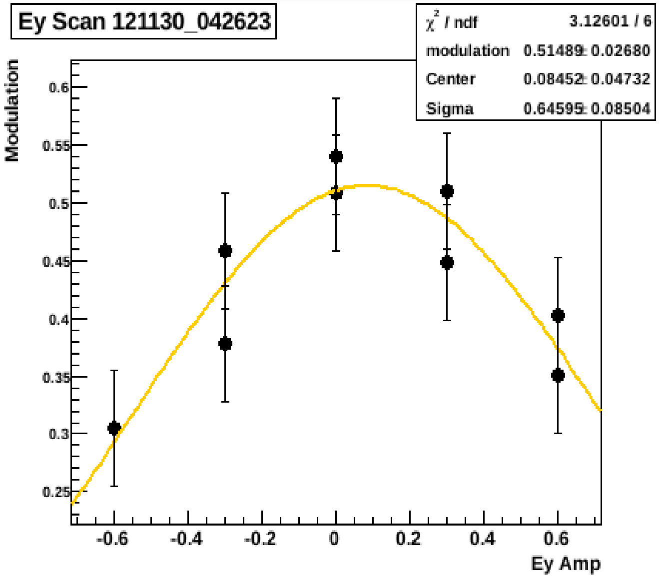
Vertical Waist



Coupling

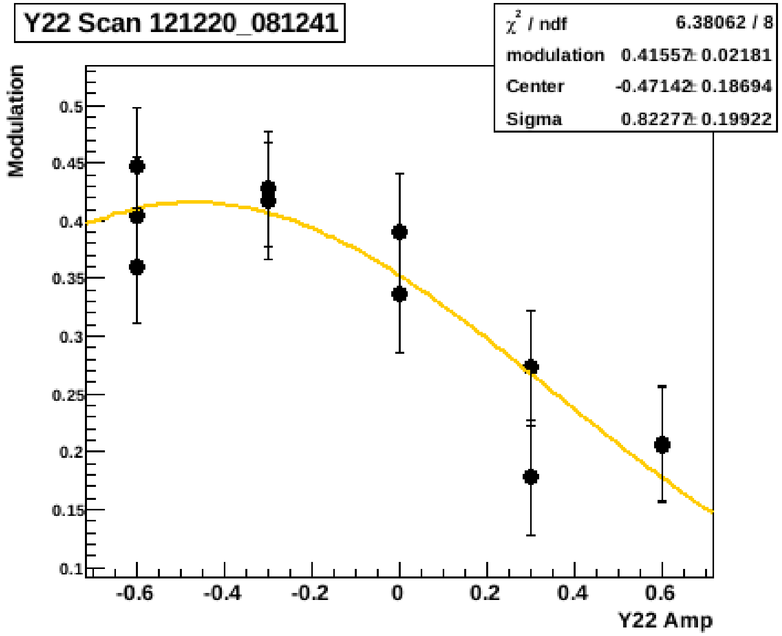


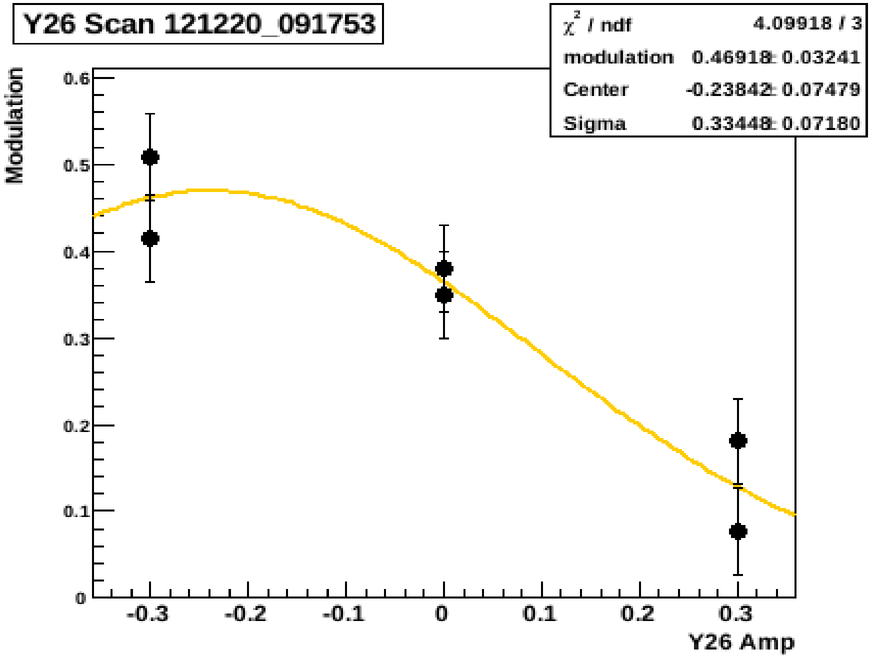
Vertical Dispersion



- Design multiknobs using model to orthogonally tune waist, coupling and dispersion at IP
  - Use co-ordinated horizontal and vertical moves of 5 FFS sextupoles
- Orthogonality looks good, once a given knob set subsequent scans are centred at zero.

IP Multi-Knob Scans (non-linear)

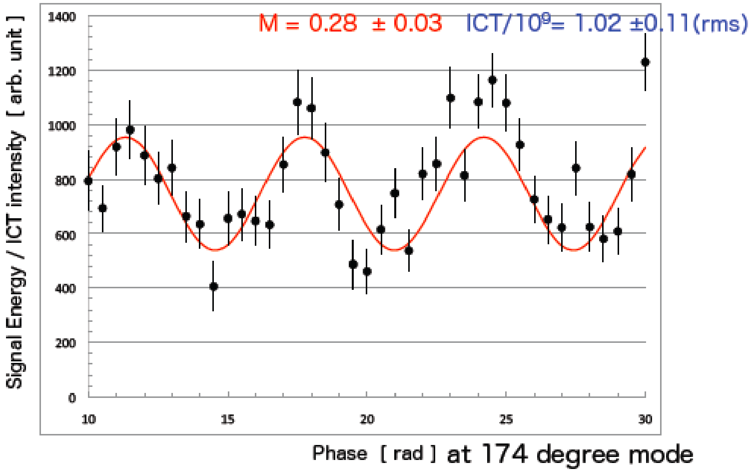




- Non-linear knobs devised using 4 skew-sextupole strengths
- Two effective non-linear knobs used
  - Y22 (second-order coupling of Y from X’)
  - Y26 (second-order chromo-geometric term)
- Need to understand if these knobs required due to multipole components in magnets or due to

Preliminary Results and Comparison with FFTB

Preliminary ATF2@KEK meas121221_183019



M = 0.28 ± 0.03 ICT/10^9= 1.02 ±0.11(rms)

at 174 degree mode
266nm/pitch

FFTB@SLAC

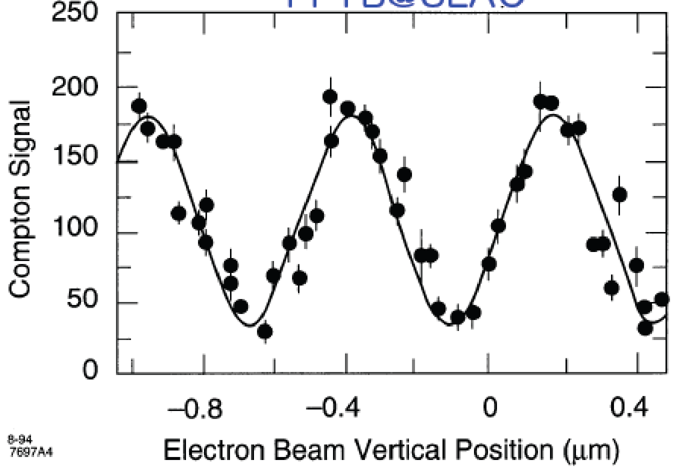
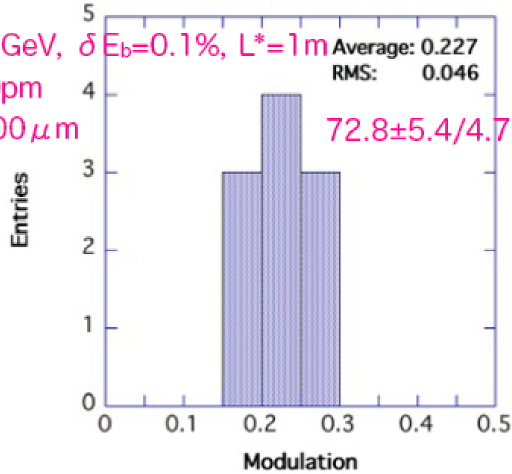


Figure 5.6: Laser-Compton beam size measurement performed in May of 1994. The measured size is 77±7 nanometers.

Preliminary

Modulation for 174deg Mode
2012/12/21

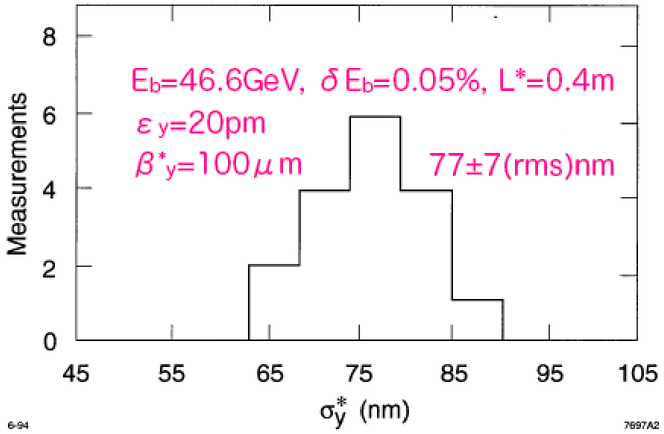
Both assumes no modulation reduction



E_b=1.3GeV, δE_b=0.1%, L*=1m
ε_y=20pm
β^*_y=100μm

72.8±5.4/4.7(rms)nm

rms of laser size = 17/12um



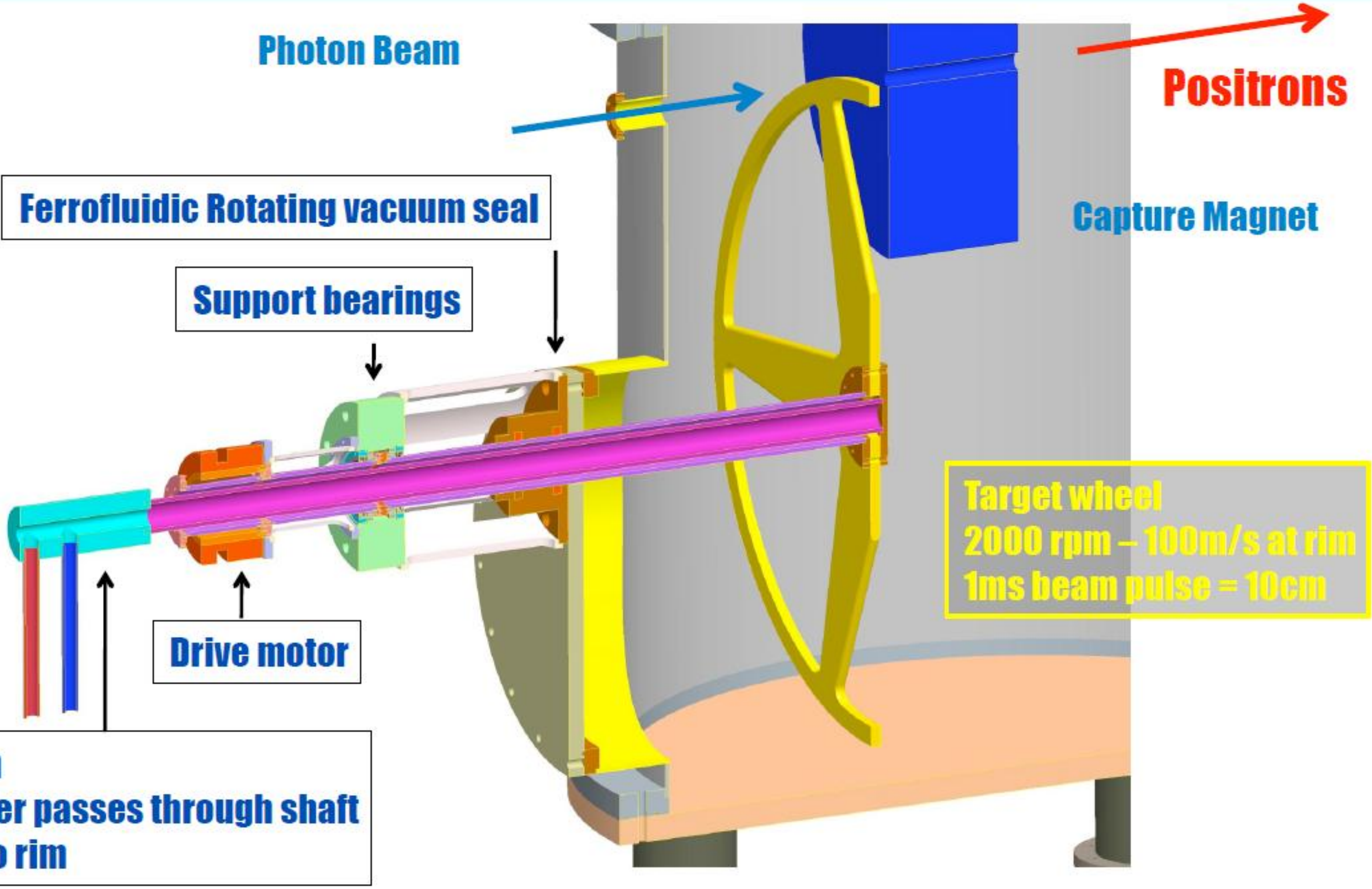
E_b=46.6GeV, δE_b=0.05%, L*=0.4m
ε_y=20pm
β^*_y=100μm

77±7(rms)nm

Figure 5.7: Histogram of measurements made during the last 3 hours of the May, 1994 FFTB run. Average size measured was 77 nm, with an RMS of 7 nm.

rms of laser size = 50um -> M reduction of 10%

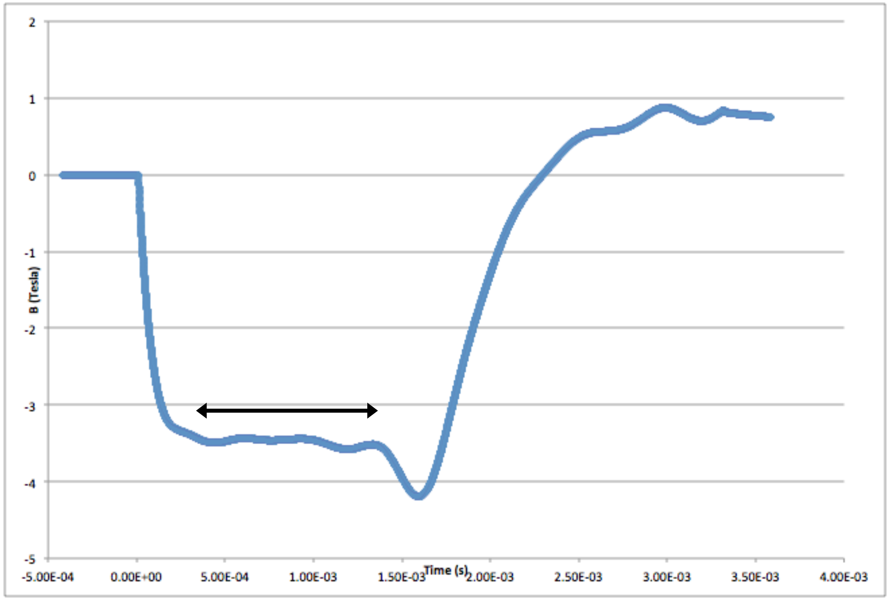
We are doing design and prototyping of the rotating shaft seal and the capture magnet



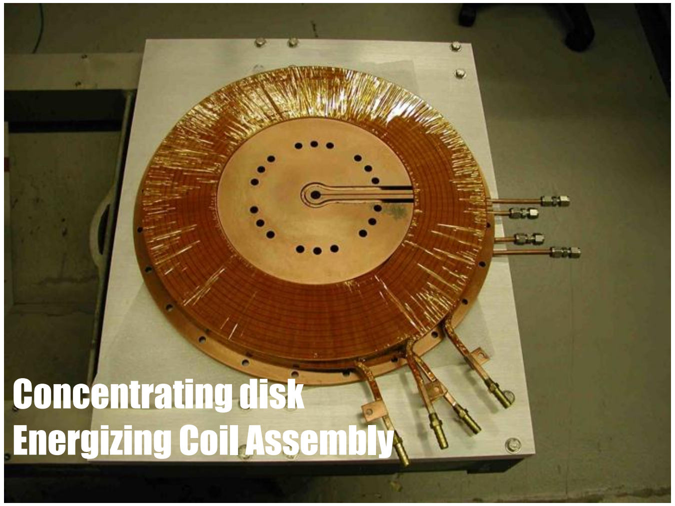
Target wheel
2000 rpm – 100m/s at rim
1ms beam pulse = 10cm

Water Union
Cooling water passes through shaft
Up spokes to rim

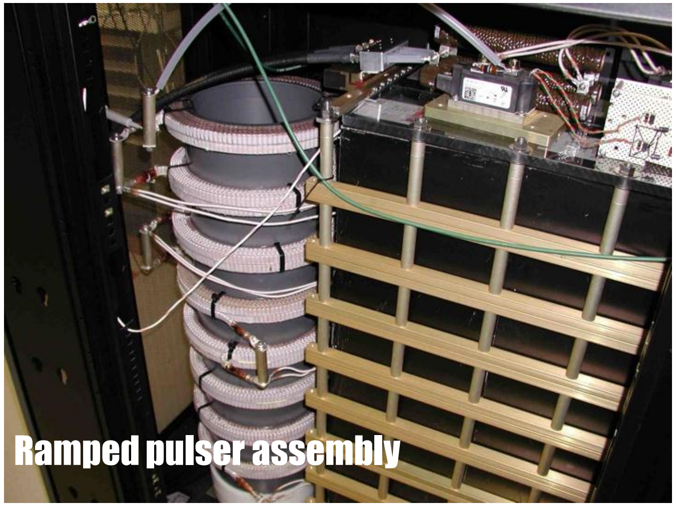
Pulsed flux concentrating magnet demonstrated 1 ms flat top with 3.5 T



- Demonstration of flat top at full field has been successful

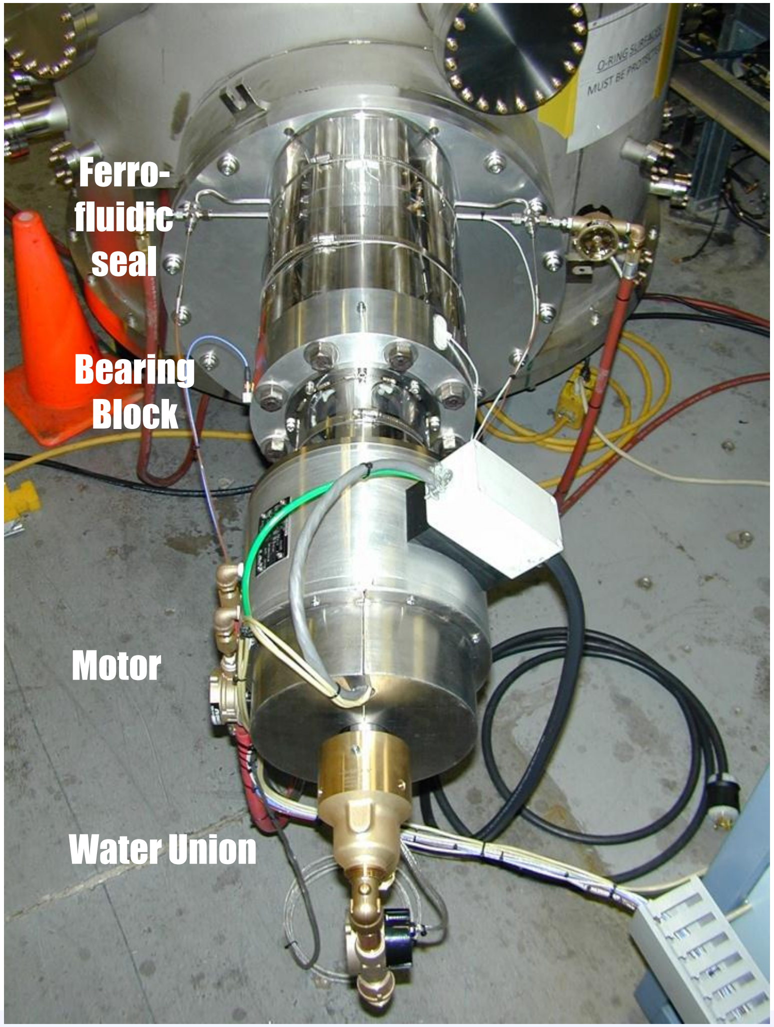


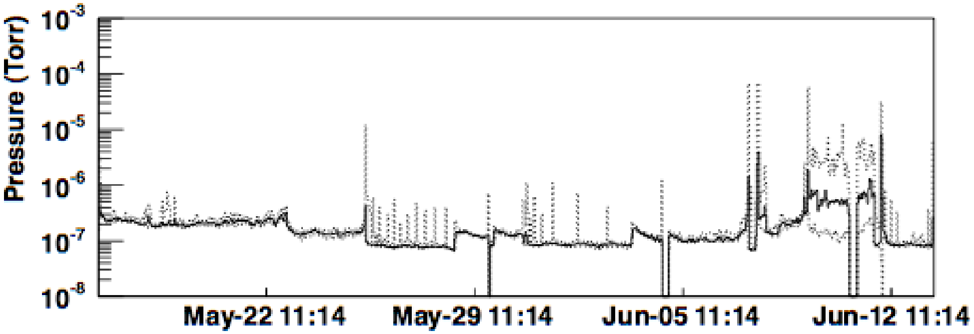
Concentrating disk
Energizing Coil Assembly



Ramped pulser assembly

Encouraging initial results from the FerroTec seal for the rotating target wheel





- Seal ran well for 450 hours before other components failed.
- Repaired system is ready for further tests as funding allows

KEK Roadmap is updated

KEK established its first Roadmap (5 year plan) in 2008, and has been carrying out its research activities according to this roadmap.

The current KEK Roadmap is available at http://legacy.kek.jp/Roadmap/index-en.html

Update of the KEK Roadmap is underway .

Update schedule

April 2012, Discussion started

August 2012, Interim report published (in Japanese)

December 2012, Draft Roadmap complete

Early 2013, Review

Spring 2013, New Roadmap complete

Provided by Yasuhiro Okada (KEK), 26/09/12

Japanese interest in hosting ILC:

- Subcommittee on the Future Projects of High Energy Physics first recommendation (submitted to ESPG):
  - "Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e+e- linear collider."
- KEK Road Map update underway
- ILC seen by some as a path toward regional (read 'far from Tokyo') economic / intellectual viability(http://www.policycouncil.jp/en/index.html):
  - "Realize a global city that attracts talent and investment from around the world: Regional development initiated by the International Linear Collider (ILC)"
- Satoru Yamashita (U. Tokyo) 23.04 'KILC' plenary last slide:
  - "So much efforts have been made. Still more and more to go in international aspects and domestic issues. But road to make it happen is getting more and more solid. Clear and timely voice of the world HEP community and the global proposal as solid as possible are the most essential to realize ILC in near future."

Japanese ILC-related groups: Summary (1)

- Advanced Accelerator Association… (AAA)
  - Established 06.2008, Industry – Government – Institution
  - Published ILC-related reports
- Federation of Diet Members for promotion of ILC Project
  - (Supra-partisan)
  - Kickoff 07.2008
  - → This group should contact US Govt ← in 2013. (my hope).
- High Energy Physics Committee (chair T. Mori)
  - Elected from J. Association of HEP
  - Report early this year
  - Subcommittee on Future Projects
- ILC Strategy Council
  - Formed 05.2012, in response to positive recommendation of HEPC

Japanese ILC-related groups: Summary(2)

- Japan Policy Council
  - » Retired politicians and industrialists
  - » Important recommendation, 07.2012 on creation of ‘science city’ with ILC at core.
- Science Council of Japan
  - » “Science Council of Japan was established in January 1949 as a "special organization" under the jurisdiction of the Prime Minister for the purpose of promoting and enhancing the field of science, and having science reflected in and permeated into administration, industries and people's lives.
  - » Following are its two functions:
    1. To deliberate on important issues concerning science and help solve such issues.
    2. To make coordination among scientific studies to achieve higher efficiency.”
  - » Hiroaki Aihara (Tokyo U) is one of ~ 200 members of the Council General Assembly

2013 – 2014

(part of the puzzle)

- Science Council of Japan: Evaluation and Ranking
  - 'Master Plan' (~30 physics projects; 2 to 3 year cycle)
  - Science-driven evaluation; includes project information
  - 'CSS (Snowmass)' / Euro SG process important
  - Complete 04.2014
- Ministry of Education (MEXT): Roadmap
  - Complete ~end 2014
  - Project maturity and community consensus
  - (Includes all MEXT projects)

Extra